

# VU Research Portal

## The loyal dissident: N.A. Bernstein and the double-edged sword of Stalinism

Meijer, O.G.; Bruijn, S.M.

### **published in**

Journal of the History of the Neurosciences  
2007

### **DOI (link to publisher)**

[10.1080/09647040600720979](https://doi.org/10.1080/09647040600720979)

### **document version**

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

### **citation for published version (APA)**

Meijer, O. G., & Bruijn, S. M. (2007). The loyal dissident: N.A. Bernstein and the double-edged sword of Stalinism. *Journal of the History of the Neurosciences*, 16(1-2), 206-224.  
<https://doi.org/10.1080/09647040600720979>

### **General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

### **Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

### **E-mail address:**

[vuresearchportal.ub@vu.nl](mailto:vuresearchportal.ub@vu.nl)

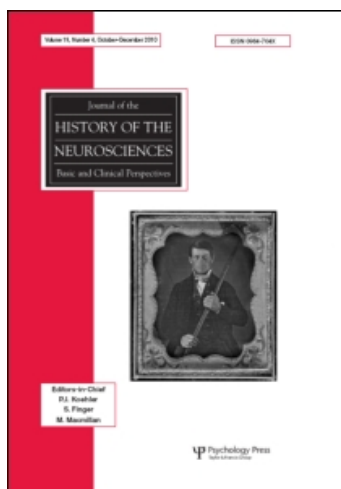
This article was downloaded by: [Vrije Universiteit, Library]

On: 9 June 2011

Access details: Access Details: [subscription number 907218003]

Publisher Psychology Press

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Journal of the History of the Neurosciences

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713658018>

### The Loyal Dissident: N.A. Bernstein and the Double-Edged Sword of Stalinism

Onno G. Meijer<sup>ab</sup>; Sjoerd M. Bruijn<sup>a</sup>

<sup>a</sup> Institute of Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, The Netherlands <sup>b</sup> Fujian Medical University, Fuzhou, P.R. China

**To cite this Article** Meijer, Onno G. and Bruijn, Sjoerd M.(2007) 'The Loyal Dissident: N.A. Bernstein and the Double-Edged Sword of Stalinism', *Journal of the History of the Neurosciences*, 16: 1, 206 – 224

**To link to this Article:** DOI: 10.1080/09647040600720979

**URL:** <http://dx.doi.org/10.1080/09647040600720979>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

## The Loyal Dissident: N.A. Bernstein and the Double-Edged Sword of Stalinism

ONNO G. MEIJER<sup>1</sup> AND SJOERD M. BRUIJN<sup>2</sup>

<sup>1</sup>Institute of Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, The Netherlands; Fujian Medical University, Fuzhou, P.R. China

<sup>2</sup>Institute of Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, The Netherlands

*Nikolai Aleksandrovich Bernstein (1896–1966) studied movement in order to understand the brain. Contra Pavlov, he saw movements (thus, the brain) as coordinated. For Bernstein, the cortex was a stochastic device; the more cortexes an animal species has, the more variable its actions will be. Actions are planned with a stochastic “model of the future,” and relevance is established through blind mathematical search. In the 1950 neoPavlovian affair, he came under strong attack and had to stop experimenting. It is argued that the consistency of his work derived both from both dialectical materialism and the relentless attacks of the neoPavlovians.*

### Introduction: The neoPavlovian Affair

Before the 1950 neoPavlovian coup materialized, Nikolai Aleksandrovich Bernstein (1896–1966) had been pushed aside already. His 1947 book *On the Construction of Movement* won him the Stalin Prize, but attacks ensued immediately. In the West, the 1948 Soviet Union may be known for the Lyssenko affair (Regelmann, 1980), but in the same year, another affair was brewing, allegedly in the name of Pavlov. Of course, all this had very little to do with Pavlov himself—who had been an ardent anticommunist until 1934, and who delighted in sharp debate rather than plain misuse of power. We will call the 1950 perpetrators the “neoPavlovians.”<sup>1</sup> This is how they started their attacks:

<sup>1</sup>Bongaardt, 1996; Bongaardt & Meijer, 2000; Meijer, 2002.

Although the view in the present paper is new, at least in its details, the authors heavily relied on material in Bongaardt’s PhD thesis (Bongaardt, 1996), Bongaardt and Meijer, 2000, as well as Meijer, 2002. Many colleagues shared their memories and insights with OGM, among them: Josif Feigenberg, Anatol Fel’dman, Viktor Gurfinkel, Alex Kozulin, Yakov Kots, Lev Latash, Grigori Orlovski, Lothar Pickenhain, and Mark Shik. Talking to them was incredibly stimulating and inspiring, but, it should be stressed that the present authors carry the full responsibility for this paper. The present authors thank Alla Vein and Peter Koehler for their stimulation and cooperation, gratefully acknowledging constructive remarks on an earlier version of the present paper by Jaap H. van Dieën, Hu Hai, Hamid Reza Fallah Yakhdani, Irina Sirotkina, and an anonymous referee. Mark Latash took the initiative of having a historical section in the journal *Motor Control*, spending his enormous energy and creativity in translating many of Bernstein’s papers for the first time into English, and we are all thankful to him. It is to Mark Latash, to Iosif Feigenberg, and to Lothar Pickenhain that we want to dedicate our present understanding of The Loyal Dissident.

Address correspondence to Onno G. Meijer. E-mail: o\_g\_meijer@fbw.vu.nl

Professor N.A. Bernstein's valuable and original [1947] monograph presents a profoundly erroneous characterization of the scientific creativity of the brilliant Russian physiologist I.P. Pavlov, one that belittles his importance to Soviet physiology.<sup>2</sup>

In the *Pravda* and *Sovetskii Sport*, Bernstein was accused of relying too much on foreign authors, of "hack work in the guise of science."<sup>3</sup>

The overall strategy of the coup appeared to derive from the Kremlin (Pickenhain, 1988).<sup>4</sup> A scientific committee was installed with Ivanov-Smolensky to lead the scientific attacks. June 28 through July 4, 1950, the actual meeting took place.<sup>5</sup> Bernstein was not even invited, but his pupils were standing outside the meeting hall, where the proceedings could be heard through loudspeakers (Feigenberg, personal communication). By now, there was no doubt that N.A. Bernstein was past tense:

Prof. Bernstein comes with fantastic hypotheses on the nature of movement coordination, and attempts to reject Pavlov's theory with *a priori* arguments. ... Although Bernstein's data are interesting, he has made them unusable with his totally wrong arguments which are factually, as well as methodologically, incorrect.<sup>6</sup>

During the meeting, Anokhin, Beritashvili, Luria, and Orbeli suffered most. Luria even renounced his views, disavowing Anokhin and Bernstein. In a 1951 meeting with neurologists and psychiatrists, Luria stated:

In my work, I failed to take my starting point in Pavlov's theory of the motor analyser, basing myself instead on the wrong physiological conceptions of P.K. Anokhin and N.A. Bernstein ....<sup>7</sup>

In 1953, Stalin died, and after a while, Bernstein was allowed to participate in scientific meetings again, supposedly because he was the founding father of cybernetics. But even in 1962, four years before Bernstein's death, it was clear that neoPavlovianism was still alive and kicking. Bernstein presented his "physiology of initiative" (cf. below) to the All-Union Conference on Philosophic Questions of Higher Nervous Activity and Psychology (cf. Graham, 1987), and Lekhtman responded:

<sup>2</sup>Kriachako, during the 1948 meeting of the Scientific-Methodological Council of the All-Union Committee of Physical Culture and Sports Affairs, cited by Sirotkina, 1995, p. 30. Note the combination of recognition ("valuable", "original") with rejection ("profoundly erroneous"), which was typical of the neoPavlovian affair.

<sup>3</sup>*Pravda*, cited in Sirotkina, *o.c.*, p. 31; cf. Feigenberg & Latash, 1996.

<sup>4</sup>January 12, 1948, Solomon Mikhoels was murdered, a leading figure in the Anti-Fascist Committee during the war, and famous for his work in the Yiddish Theatre. This event marked the start of Stalin's postwar antisemitic campaign (cf. Judt, 2005)—an important context of the neoPavlovian affair. Thus, Bernstein was "a cosmopolitan without a fatherland" (*o.c.*, p. 183).

<sup>5</sup>Akademija Nauk SSSR & Akademija Meditsinskikh Nauk SSSR, 1950.

<sup>6</sup>Smirnov, 1950/1954; translation from the German by OGM.

<sup>7</sup>Luria, 1951, cited in Pickenhain, 1998, p. 400, translation from the German by OGM. This episode did not hinder the friendship between Luria and Bernstein, the latter clearly understanding what had to be done in order to be allowed to continue working.

... there are serious methodological problems with [Bernstein's] conception of a "physiology of activity." This tendentious confrontation ... [with] the physiology of reflexes ... reveals ... the undeniable superiority of the latter, both regarding to facts and to methodology.<sup>8</sup>

Who was this N.A. Bernstein, so much a nail in the coffin of Pavlov, both in actual fact, and in the power-hungry reconstructions of the neoPavlovians?

The present paper is written by admirers, unfortunately not able to speak or to read Russian. Many people were willing to share their memories and views with one of us (OGM), but, of course, the present authors carry the full responsibility for this intellectual biography of "The loyal dissident." It will be argued that Bernstein's great inspiration<sup>9</sup> stems from dialectical materialism as well as the shattering unfairness of neoPavlovianism.

### Movements almost Exactly Repeat Themselves: 1922–1928

A Russian biography of Bernstein was published recently,<sup>10</sup> but for the reader of English, not much material is available.<sup>11</sup>

Although Jews were generally not granted much opportunity, the Bernstein family was relatively well-to-do, with that German-inspired mentality of the *Bürger*,<sup>12</sup> enjoying private life, serving the nation as required, and showing restraint in public life. Nikolai Aleksandrovich was born, and died, in Moscow (1896–1966), his father a famous psychiatrist, an uncle a famous mathematician. German scientific materialism<sup>13</sup> was clearly present in the intellectual background. Nikolai studied medicine, served as a doctor in the civil war after the revolution, practiced neuropsychology in Moscow and studied some mathematics, as well as music, before he was called to join the Central Labour Institute in 1922.

The institute had been Lenin's idea: Focus on the movements of the workers, make them more efficient, and economic production will increase.<sup>14</sup> But Gastev, the director of the institute, was clearly overdoing it, reducing workers to cog-wheels in the machine (Bailes, 1977). Protestors called for a more holistic approach, which would include physiology and psychology. By inviting Nikolai Bernstein to join the institute, Gastev clearly gave in and so convinced his opponents that the institute was on the right track.<sup>15</sup>

Just as his father had studied the brain through behavior, Nikolai Bernstein used movement as his looking glass to view the workings of the brain. In the 1830s, the

<sup>8</sup>Lekhtman, 1963, p. 599, translated by Ines M. Rubin.

<sup>9</sup>Ambiguity intended: The statement refers to both what made Bernstein tick, and what makes the story of his work so fascinating to the historian of science.

<sup>10</sup>Feigenberg, 2004; cf. Latash, 2005.

<sup>11</sup>See, e.g., Gel'fand et al., 1971; Feigenberg & Latash, *o.c.*; cf. Gurfinkel & Cordo, 1998, Bongaardt, 1996; Bongaardt & Meijer, 2000; Meijer & Feigenberg, 2000.

<sup>12</sup>For a telling description of this mentality, see Hafner, 1979.

<sup>13</sup>See Gregory, 1977.

<sup>14</sup>Labor and sports were of central importance to the state, first in the Soviet Union, later also in the satellite states (cf. Bongaardt, Pickenhain & Meijer, 2000). Hence, the study of "movement" was a perfectly legitimate topic in science, related to physiology and neurology, which explains the ease for Bernstein to move from the Central Institute of Physical Culture to the Institute of Neurology.

<sup>15</sup>Later, in the mid-1930s, Gastev ran in trouble. He died in Siberia, to be rehabilitated posthumously, after Stalin's death.

Weber brothers had published a book (1836/1991), arguing that in walking, the swinging leg does not, or not necessarily require muscle force, because it can give in to gravity/inertia. At the time, the book could be seen as attacking Prussian military habits (such as the goose step).<sup>16</sup> Around 1900, with Germany unified, and Prussian power greater than ever, Braune and Fischer (1895–1904) expressed their disagreement with the Webers: The will is always needed for movement. In fact, if you look at movement, you can “see” the will.<sup>17</sup> Note that this is a dualistic statement, but in Lenin’s Soviet Union there was little pressure on the content of science, and, anyhow, Braune and Fischer were the natural starting point for those who wanted to study movement.

Historically, there were two related problems in the study of biological motion. First, it is often too quick for the human eye, and film had to be invented to make it accessible. Braune and Fischer worked with film (Figure 1), and Bernstein gave great attention to its further development (Figure 2). Second, if you study the ensuing time-series, that is, the actual trajectories of moving points, what you see is rather messy (Figure 3), and you need a dedicated mathematics to understand what is going on. It would take Bernstein several years before he came in touch with such mathematics.<sup>18</sup>

Bernstein started working at a time of great hopes for many. The civil war was over, economy was doing reasonably well, and it was wonderful to partake in the shaping of a new society. Bernstein’s enthusiasm was infectious. He developed a high-speed camera, the “kymocyclograph,” with a photographic plate standing still. The shutter was a round plate, with holes in it, rotating fast before the lens, so that the photographic plate would repeatedly be exposed for a short time, and the trajectory of the movement would reveal itself with great precision (Figure 4). Here, we see Bernstein at his best: He constructed the shutter himself, but did not trust the formalisms predicting its speed, and he wanted it actually measured. He did so by blowing air through the holes, and using a tuning fork to establish the tone, i.e., the frequency, or shutter speed. At the same time, there were clear signs that he remained inspired by Braune and Fischer, stating that the graphs produced were showing:

... With great clarity the high degree of automation ... mechanical simplicity and lawful structure. (Bernstein, 1927, p. 789, as translated in Bongaardt, 1996, p. 24)

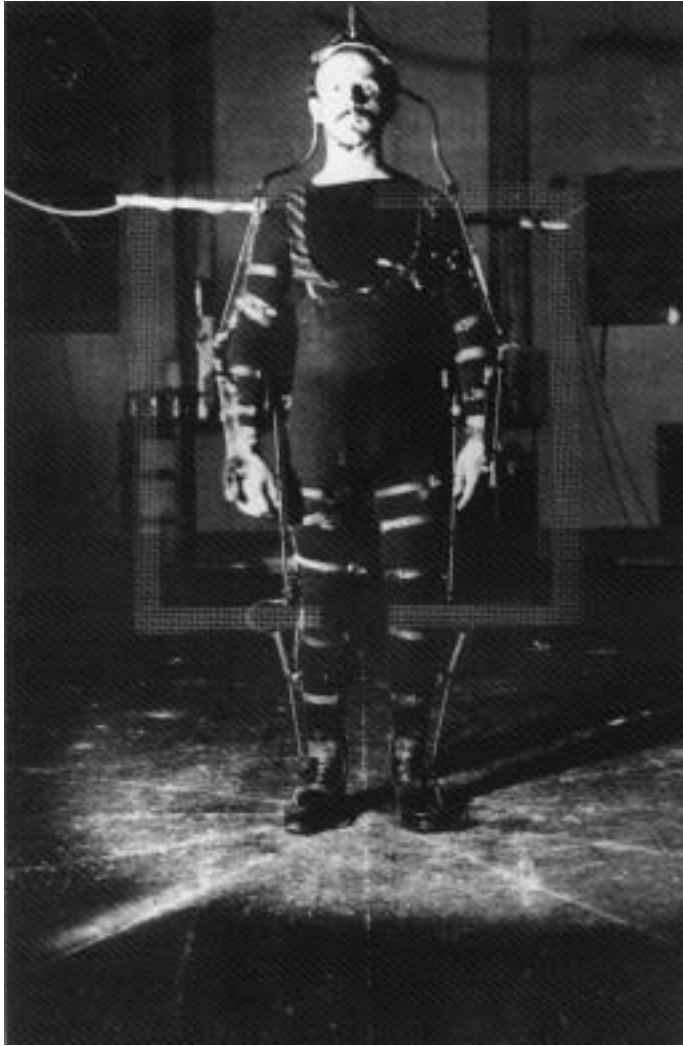
In other words, movements almost exactly repeat themselves. This may require a pause.

Since the 1500s, Europe had seen the working of the locomotor apparatus as that of an automaton, producing the required movement with clockwise precision (Meijer, 2001;

<sup>16</sup>See Flesher, 1997. For the Prussian military, the soldier had to be in continuous command of his own body (more or less similar to the way the authorities had to be in command of the citizens). The Prussian army had lost big time from Napoleon in 1806 (Jena and Auerstädt), maybe in part because soldiers had overexhausted themselves by walking ridiculously. Of course, the Weber brothers do not mention these events explicitly in their book. Still, these were dangerous times. Gymnastics had been forbidden by the Prussian government (*die Turnsperr*, 1819–1842, cf. Ueberhorst, 1980), because it was too closely associated with liberalism. And in 1837, Wilhelm Weber actually ran into political problems, that is, by joining with the *Göttingen Seven* in opposing the monarch of Hannover, who had just cancelled the liberal constitution.

<sup>17</sup>Bernstein found no biological attraction in the free will, and his inspiration by Braune and Fischer’s work was to be relatively short-lived (see below; Meijer & Wagenaar, 1998).

<sup>18</sup>See the next section, in particular Bernstein’s meeting with Tatiana Popova.

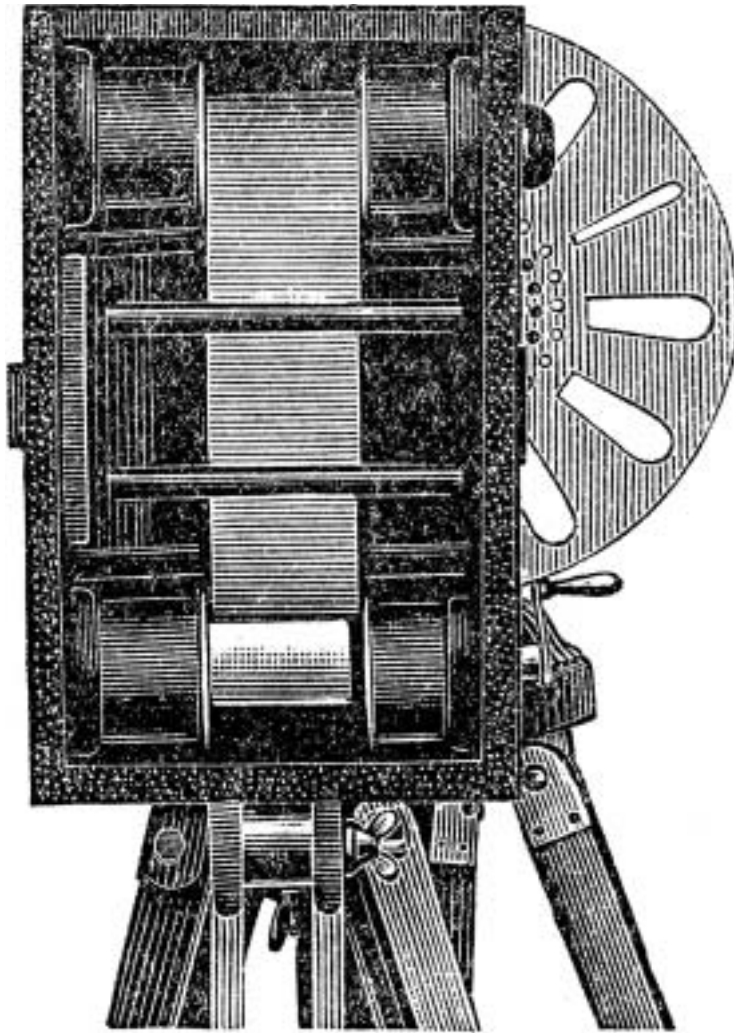


**Figure 1.** Man standing ready to be filmed while walking (from Braune & Fischer, 1895–1904, page without number).

Huxley, 1874/1893). The trouble is that mechanical systems cannot control themselves (Gel'fand & Latash, 1998), and so, science started to search for “something else” to do the control, e.g., “the soul,” or, in late nineteenth century, “the will.” Dualism and the belief that the locomotor system is a perfectly predictable mechanical system are two sides of the same coin. By emphasizing the mechanical automation of overt movement, Bernstein implicitly followed Braune and Fischer’s understanding of the free will. Of course, this was to change.

### **Movements Never Exactly Repeat Themselves: 1929–1936**

In the 1920s, one could find Bernstein cooperating with musicologists, talking to mathematicians, working in Kornilov’s laboratory for Experimental Psychology, and publishing



**Figure 2.** Bernstein's kymocyclograph (from "Movements," *Grand Medical Encyclopaedia*, 1929; cf. Fel'dman & Meijer, 1999, p. 128).

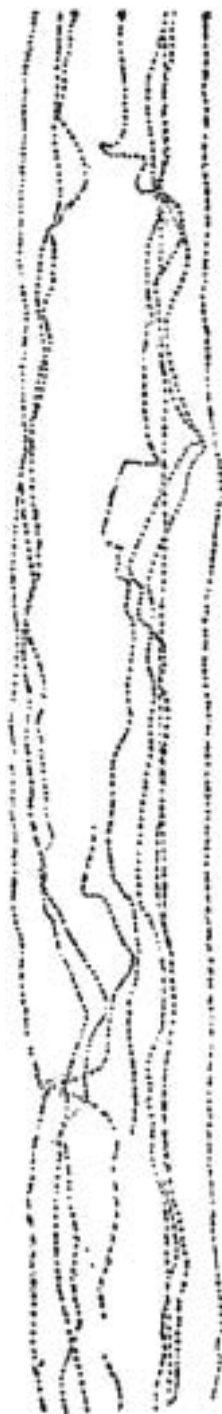
a *Practice of Experimental Psychology* with Luria and Vygotsky.<sup>19</sup> He often used encyclopaedia articles as a playing ground to develop new ideas. In a *Grand Medical Encyclopaedia* article, published 1929, we find the rather amazing statement that "There are no situations in which muscle shortening is the cause of a movement."<sup>20</sup> Bernstein argues that the organism is always subject to many forces (gravity, inertia, walking against the wind, etc.), rendering it inconceivable that one, isolated muscle contraction "causes" the whole structure of a movement. One year later, he states: "No movement can be entirely planned from its very beginning."<sup>21</sup> Whatever the commanding signals, unexpected things will

<sup>19</sup>Published in 1927, cf. Feigenberg, 1988.

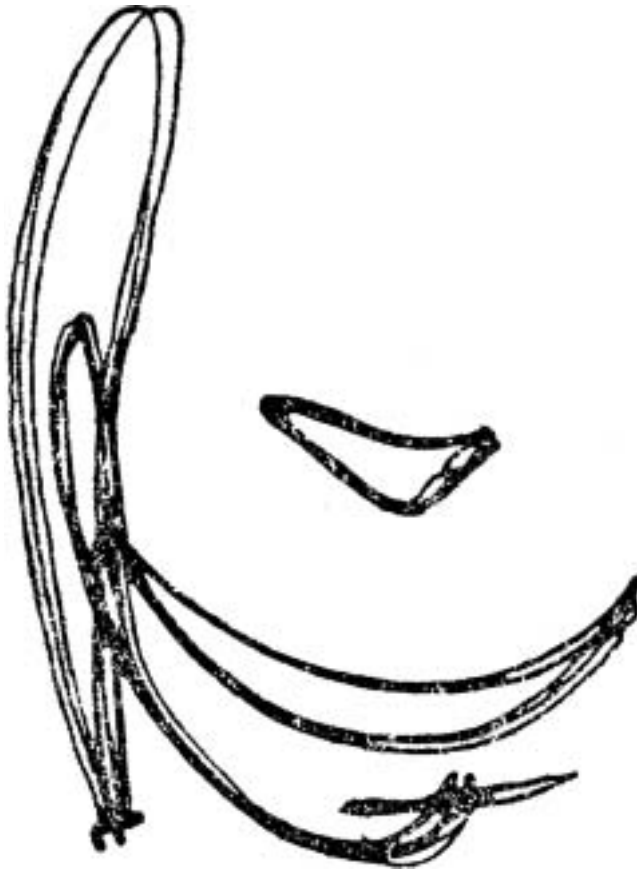
<sup>20</sup>Cited from Fel'dman & Meijer, 1999, p. 119.

<sup>21</sup>Published in 1930, cited from Beek & Meijer, 1999, p. 5.





**Figure 3.** Kymocyclogram of recharching a rifle (from “Movements”, *Grand Medical Encyclopaedia*, 1929, with the addition “author’s data”; cf. Feld’man & Meijer, 1999, p. 114).



**Figure 4.** Cyclogram of three successive strikes by a blacksmith (from “Movements”, *Grand Medical Encyclopaedia*, 1929; again with “author’s data,” and also “automatic nature of learned movements,” an interpretation Bernstein was about to leave; cf. Fel’dman & Meijer, 1999, p. 113).

happen, and continuous correction is needed. In other words, since the brain is an organizer, the brain itself must be organized.<sup>22</sup>

By 1929, Bernstein had met with Tatiana Popova, a gifted mathematician and scientist with a clear interest in music. In the title of their joint paper, “Studies on the Biodynamics of the Piano Strike,” the term “mechanics” is replaced with “dynamics.” More important, self-organized oscillators appear, completely alien to Bernstein’s earlier writings:

During slow and medium tempi, both the hand and the forearm move under the action of their own active muscle impulses. At medium tempi, a sequence of such impulses merges into a single continuous chain ... During tempi over about 6.5 strikes per second ... hand motion transforms into forced elastic oscillations of a rather simple construction, with force amplitude close to the theoretical minimum.<sup>23</sup>

<sup>22</sup>This argument, central in Bernstein 1935/1988, derives from typical *Gestalt* reasoning and may not be seen as a legitimate argument by all, particularly not by Pavlov, who despised *Gestalt* for its lack of scientific rigor (cf. the quote at the end of the present paper).

<sup>23</sup>Cited from Kay, Turvey & Meijer, 2003, p. 38.

“Oscillations” belong to the great tradition of Poincaré, Krylov, and Lyapounov. In 1931, Adrian and Buytendijk would claim that respiration depends on an oscillator in the brain stem. A formal “Theory of Oscillations” was to be published, in 1937 (cf. 1937/1949), by Andronov and Chaikin. The thing with oscillators is that they *fill-in the details themselves*. Take your plastic ruler, let a large part of it stick out from the edge of the table, hit it repeatedly with a finger, and it will find its own rhythm. Thus, there is no 1:1 relationship between the commanding signal (the hitting finger), and the ensuing movement.

In his 1929 paper with Popova, Bernstein definitively broke with the views of Braune and Fischer. His new, more “dynamical” view was more in agreement with dialectical materialism (Graham, 1987<sup>24</sup>; Meijer, 2002). Consequently, his opinion on Pavlov’s work was turning more negative. In fact, he had rejected the validity of Pavlov’s theory of conditioned reflexes as early as 1924,<sup>25</sup> but, until 1929, he failed to reach consistency and continued to be inspired by Braune and Fischer. Some of his doubt is visible in a poem Bernstein happily wrote in 1926, in response to Nemlicher’s humorous ridiculization of Pavlov:

... Yes, I do not trust Pavlov one iota. ...  
 Nothing is clear, and the human mind is helpless,  
 But I will pierce with the reflex all the rubbish about the soul and will.  
 I know only one thing: I can accept the nonsense of free will  
 Not more than the myths about fatum.  
 Life tells you “a” and you reply “b”—Nothing more.  
 Let Pavlov be an ape,  
 But our grandfathers were apes as well ...<sup>26</sup>

This 1926 poem conveyed critical admiration. The admiration would remain, but, from 1929 onwards, the criticism would continue to grow.<sup>27</sup>

In Pavlov’s physiology of higher nervous activity, cortical cells were responsible for the unfolding of the conditioned reflex. Critics would say that Pavlov’s view of the brain was too static, but Pavlov himself was not, and, in the 1930s, he acknowledged that the

<sup>24</sup>Graham (1987) dedicated a special paragraph (pp. 192–197) to Bernstein’s rejection of Pavlov’s reflex approach. Graham may well have been the first to point out the importance of dialectical materialism for the *content* of Soviet physiology and psychology. As to Bernstein, however, his analysis is mainly based on Bernstein’s views *after* the neoPavlovian coup. The present analysis differs with Graham’s in two respects. First, although the road from German scientific materialism to dialectical materialism may seem short, it took Bernstein from 1922 to 1929 to reach consistency in this respect. Second, after the neoPavlovian affair, he continued on this road, now going to its extremes, thereby enlarging rather than softening the differences with the neoPavlovian approach.

<sup>25</sup>This was pointed out to us by Irina Sirotkina, whose comments on Bernstein’s 1924 “Work Movements and Conditioned Reflexes” appeared in 1996.

<sup>26</sup>Bernstein, 1926, as cited in Latash, *o.c.* Note that it is virtually impossible to retain the precise meaning of a poem in translation, particularly if the poem is meant to be humorous. The least one can say about this poem is that it conveys ambivalence. This ambivalence remained with Bernstein for the rest of his life. Pavlov, after all, had received the Nobel Prize for his epoch making work on the digestive system, and then he had discovered the conditioned reflex. Nobody would contest that these had been great discoveries.

<sup>27</sup>Maybe because his views had matured, certainly because he had met with Tatiana Popova, and possibly (although we ourselves don’t think so) because the regime had started to interfere with the content of Soviet science.

connections were temporary (Pavlov, 1932a/1955), and that there was a dynamic stereotypy (1932b/1955) in the mosaic of cortical functions (1934a/1955). For Pavlov, the cortex was a kaleidoscope of cells connecting input to output, true, a changing kaleidoscope, but whenever you knew the input, you could predict the output. Bernstein disagreed.

These were the years, 1928/1929, when the government started to interfere with membership of the Academy of Sciences. Pavlov was furious, and during a celebration of the 100th anniversary of Sechenov's birth, he fulminated in front of a shocked audience:

Oh noble and stern apparition [i.e., Sechenov]! How you would have suffered if in living human form you still remained among us! We live under the rule of the cruel principle that the state and authority is everything, that the person, the citizen is nothing. ... On such a basis, gentlemen, not only can no civilized state be built, but no state at all can long survive.<sup>28</sup>

Pavlov's idiosyncrasy towards the government was the epitome of political incorrectness, and dialectical materialism (cf. Graham, 1987<sup>29</sup>) cannot be reconciled with Pavlov's mechanistic views of the brain. Wasn't this the time for a reshuffling of power? But then, who was there to take the lead? Bekhterev was dead,<sup>30</sup> and Kornilov would be denounced shortly (Kozulin, 1984). Bernstein may have been an attractive candidate, but for Bernstein himself, power play was totally out of character.<sup>31</sup> Still, he was the great hero in the life of Tatiana Popova, and it appears<sup>32</sup> that she dreamt of a great future for this inspiring, handsome man (Figure 5).

As if oblivious to grand politics, and grand emotions, Bernstein continued his work with tenacity. Stimulated by Popova's understanding of the workings of oscillators, he concluded that the global structure of the movement remains the same (Figure 4), while the (details of the) movements never exactly repeat themselves. In his "anti-Pavlov"<sup>33</sup> paper (1935/1988), this global structure became the "topology," or the "coordination" of the movement. Ultimately, his notion of "coordination" would give him world fame, but the timing of the paper could not have been worse.

In 1934, when Hitler had come to power in Germany, Pavlov decided that Stalin was a lesser danger to mankind and "converted" to Soviet communism, writing that "... we should especially sympathize with and facilitate our government's struggle for peace."<sup>34</sup> In 1935, the year of Bernstein's paper on coordination, Pavlov himself was president of

<sup>28</sup>Pavlov, 1929, quoted from Todes, 1995, p. 400.

<sup>29</sup>Interestingly, Grachenkov characterized Pavlov's reflex approach as "mechanistic" in the 1930s (Graham, *o.c.*, p. 197), that is, around the same time that Bernstein would launch his attack on Pavlov's views. Grachenkov and Bernstein were to remain friends.

<sup>30</sup>To the best of our knowledge, the rumor that he was killed by the Kremlin because he knew too much (as published in Kozulin, 1984) was, and remains, unsubstantiated.

<sup>31</sup>Witness his decision to cancel the publication of his "anti-Pavlov" book after Pavlov's death (see below).

<sup>32</sup>In the 1930s, she would marry Bernstein's brother, but after her death, it turned out that she had changed her home into somewhat of a museum of Nikolai Aleksandrovich (Feigenberg, personal communication). Although she remained relatively unknown, Bernstein continued to refer to her work in his publications. But he married someone else.

<sup>33</sup>That is, anti Pavlov's theory of higher nervous activity, emphatically not a personal attack against the man, nor an attempt to belittle his earlier discoveries.

<sup>34</sup>Pavlov, 1934, cited from Todes, *o.c.*, p. 412.



**Figure 5.** Nikolai Aleksandrovich Bernstein (courtesy of Mark L. Latash).

the 15th International Congress of Physiologists in Russia (Moscow and Leningrad), ending his opening address with the words:<sup>35</sup>

... We, Russian physiologists, wish to express gratitude to our government which has enabled us to receive our esteemed guests in a worthy manner.  
(*Applause.*)

Not a very good year, then, to claim that this exalted man, Ivan Pavlov, was entertaining a wrong theory of higher nervous activity.

In 1929, it may have seemed politically correct to replace “mechanics” with “dynamics,” and Bernstein himself was to remain inspired by dialectical materialism. Stalin, on the other hand, never was a good communist, and now, the terror was starting: the mass murder of Ukraine Kulaks, and soon, the purges.<sup>36</sup> Citizens had to find their sanity in the ordinary things of life.<sup>37</sup> for Bernstein, such an ordinary thing was publishing science, and in 1936, he received and corrected the galley proofs of his new book that was to take Pavlov’s brain theory completely apart. Then, Pavlov died, and Bernstein thought it not

<sup>35</sup>Pavlov, 1935/1955, p. 58.

<sup>36</sup>For a chilling description see Aksyonov, 1993–1994, which depicts how alleged dissidents were invited to visit a brightly lit, white-washed room, where they were shot in the neck, falling forward on a moving treadmill, so that the body could be transported automatically onto the waiting truck.

<sup>37</sup>Aksyonov, 1993–1994; Orlovsky, personal communication; Bongaardt, Pickenhain & Meijer, *o.c.*

appropriate to attack a dead man. He cancelled publishing the book.<sup>38</sup> Thus aborted his first attack of Pavlov's theory of higher nervous activity. Bernstein used the remaining 30 years of his life to develop a brain theory that would do justice to biology.

### The Biology of the Blind Controller: 1936–1966

Darwin's biology was stochastic, but the theory of oscillations was not, at least not until the 1960s.<sup>39</sup> Nevertheless, from 1936 onwards, Bernstein's understanding of the organization of the brain gave an important place to stochasticity.

He frantically worked at the Laboratory for Biomechanics of the Central Institute of Physical Culture, later became director of the Movement Laboratory of the Institute of Neurology.<sup>40</sup> He studied sports, work, and movement pathology,<sup>41</sup> further developed his theory of the brain, and he often published on topics of general interest. On June 22, 1941, Hitler attacked the Soviet Union, and when German armies approached Moscow, many citizens fled, or were forced to evacuate. Bernstein and his wife went to Siberia, and later joined his brother in Tashkent. In 1945, sharing the general elation of having won the war, he addressed a conference dedicated to the 300th "anniversary of the idea of reflex and paying homage to its founder, Descartes, and to the great Russian scientists Sechenov and Pavlov."<sup>42</sup> *Sic*. The audience was in for some amazing statements:

Since the emergence of (a) the telereceptive function of the head end of the body, (b) the integrative function of the nervous system, (c) jointed skeletons and striated muscles, and (d) neokinetic, "telegraph" spike processes, bioelectrical by nature, the ancient, humoral paleoprocess has regulated the powerful but blind discharge of the neospike.<sup>43</sup>

Once more, pause is due. Our head serves to perceive at a distance, and it is the function of the brain to integrate such information (per implication, to integrate our actions). Our locomotor system, with striated muscles, allows for precise control, but only blind commands can be given—long-distance action potentials, stochastic events travelling along telegraph wires. The controller is like a general ordering his soldiers to take a certain hill, unable to specify how exactly they may do that.<sup>44</sup> In the nervous system, actual regulation resides in the lower, older levels, being of a chemical rather than electrical nature. Note that this turns Sherrington's view (e.g., 1906) on its head: The amazing thing about the nervous system is not so much the intelligence of the higher levels—the higher levels are about stochasticity. It is the lower levels that ensure biological function, a thought still

<sup>38</sup>In 2003, it was published in Russian (Bernstein, 1936/2003).

<sup>39</sup>See, e.g., Haken, 1977; Prigogine & Stengers, 1984.

<sup>40</sup>Given his tendency to collaborate with many different groups, it is difficult to reconstruct the precise history of Bernstein's institutional affiliations. To the present authors, it is not exactly clear when he was invited to join Institute of Neurology, nor, for that matter, when exactly he was invited to become corresponding member of the Academy of Medical Sciences (clearly, with the help of his friends, such as Grachenkov).

<sup>41</sup>See Wagenaar & Meijer, 1998.

<sup>42</sup>Bernstein, 1945, in Sporns, Edelman & Meijer, 1998, p. 286.

<sup>43</sup>Bernstein, 1945, in Sporns Edelman & Meijer, *o.c.*, p. 294.

<sup>44</sup>See Greene, 1972. Note that the biological nature of the "controller" becomes difficult to envisage. It is certainly not a single cell in the cortex. In a 1966 paper by Bassin, Bernstein, and Lev Latash (cf. Latash, Latash & Meijer, 1999 & 2000), Bernstein would argue that during every action the whole brain is involved.

against mainstream neuroscience, but logically the only way the brain can have evolved. Bernstein's brain belongs to biology.

This dynamical<sup>45</sup> hierarchy was to be the central theme of his book *On the Construction of Movements* (1947), which made him famous and precipitated his fall. Simultaneously, he worked on another book, not published during his lifetime, but by now translated into English: *On Dexterity and its Development* (1945–1946/1996). Dexterity, he argues, is not that animals know the perfect solution to motor problems, dexterity implies that their every act is different from its predecessors. The more cortical cells a species has, the less stereotyped its behavior. Thus it is that organisms can learn. At the time, neoPavlovianism prevented publication, and, after the 1950 meeting, Bernstein was fired. These were the years of Stalin's second wave of purges.<sup>46</sup> Bernstein and his wife started to take morphine every afternoon (Feigenberg & Latash, 1996), while in the mornings, he would meet and discuss with his students and his peers. Thus, he could continue working, although officially forbidden to do so. More amazingly, he never turned disloyal to communism and dialectical materialism.<sup>47</sup>

After Stalin's death, Bernstein was allowed to work again, now entering a phase of theoretical rather than laboratory studies. He would argue that biological organisms are active, that is to say, they act upon their environment. Given a need, they will use a stochastic model of the past-present (predicting the possible consequences of potential actions), then go for the full 100% for one action, implying a collapse of the probability model.<sup>48</sup> This "physiology of initiative"<sup>49</sup> would bring him ridicule from the neoPavlovians, but in Bernstein's view, actions are not controlled by the future, they are controlled by a model of the future (cf. Feigenberg & Meijer, 1999).

In the course of this work, Bernstein would meet with the mathematical giant Gel'fand,<sup>50</sup> and with inspiring Tsetlin, who were elaborating a mathematical theory of searching: How can a blind network solve problems?<sup>51</sup> By varying the values of variables, and then

<sup>45</sup>"Dynamical" because which level would do what would be dependent upon the task at hand. In fact, given the task, a specific division into different levels will take place first.

<sup>46</sup>"The scale of the punishment meted out to the citizens of the USSR and Eastern Europe in the decade following World War Two was monumental—and, outside the Soviet Union itself, utterly unprecedented. [Show] trials were but the visible tip of an archipelago of repression: prison, exile forced labor battalions. In 1952, at the height of the second Stalinist terror, 1.7 million prisoners were held in Soviet labor camps, a further 800,000 in labor colonies, and 2,753,000 in 'special settlements.' The 'normal' Gulag sentence was 25 years, typically followed (in the case of survivors) by exile to Siberia or Soviet Central Asia" (Judt, *o.c.*, pp. 191–192).

<sup>47</sup>Witness his 1957 discussion of Lenin's theory of knowledge: "... knowledge through action and *revision through practice* which is the cornerstone of the entire dialectical materialistic theory of knowledge, and ... serves as a sort of biological context for Lenin's theory of reflexion" (Bernstein, 1957, in the 1967 book, p. 120; cf. Bongaardt, 1996).

<sup>48</sup>Conceptually, this is related to the measurement problem in quantum mechanics.

<sup>49</sup>Note that this theory forms Bernstein's most principled attack on Pavlov's theory of higher nervous activity. In 1935, Bernstein proposed to regard the brain as coordinated, while one could argue that Pavlov lacked a theory about the organization of the brain. Bernstein's work on stochasticity and the dynamic layering of the brain can be seen as theoretically neutral and was not in contradiction with anything Pavlov had stated in the 1930s. The "physiology of initiative," however, clearly ran against the hard core of Pavlov's theory. Interestingly, this theory was formulated after the neoPavlovian coup.

<sup>50</sup>Israel Gel'fand (born 1913) is one of the most outstanding mathematicians of the twentieth century. He did his PhD (1935) with Kolmogorov, published a large number of monographs on a variety of topics, and he wrote important textbooks for mathematical education. In 1958, he became interested in biology and medicine and started, with Fomin, the Institute of Biological Physics. Three times he was awarded with the Order of Lenin. He was elected honorary member of scientific societies in many countries, and he received several honorary doctorates, including one from Oxford University. In 1989–1990, he taught at Harvard and in 1990 also at MIT. In that year, he emigrated to the United States.

<sup>51</sup>Gel'fand & Tsetlin, 1961.

“seeing” what the consequences are! If these consequences are large, the variable in question is “essential.” So, what you need for blind search is a tendency to vary, and some optimisation criterion, both clearly properties of biological systems. In the Moscow Institute for Biological Physics, later in the Institute for Information Transmission, a movement-dedicated group of researchers formed, informally called “the Bernstein school,” or “the Gel’fand school”—both labels appear appropriate. It was a tightly knit group, even enjoying holidays together. Bernstein now realized that the variability of movement execution (of the details, as different from the overall coordination) revealed search behavior in the sense of Gel’fand and Tsetlin:

... those aspects of the remaining variability that have no reactive adaptive value can justifiably be looked upon as *search-variability*, in which the active exploration of the environment, its gradients, the optimal way to act, *et cetera*, come to the fore.<sup>52</sup>

In 1965, Bernstein knew that he was suffering from kidney cancer. He received his pupils and discussed their future with them, remaining incredibly active himself,<sup>53</sup> until one day in 1966, Luria called Bernstein’s friends and brought the devastating news: Nikolai Aleksandrovich had died. None of the traditional (neoPavlovian) institutes wanted to host the funeral, but, while the director of the Institute of Higher Nervous Activity was away in the Soviet Far East, and an assistant agreed. So it came to be that “Pavlov’s portrait was staring down at Bernstein’s coffin” (Bongaardt, 1996, p. 47) when Gel’fand took the chair and read a poem by Boris Pasternak:

To give your all—this is creation  
And not to deafen and eclipse  
How shameful when you have no meaning  
To be on everybody’s lips!<sup>54</sup>

## A Moscow Renaissance

Students of movement are still baffled by the incredible creativity that emerged from Moscow in the late 1960s. A large number of inspiring studies sprung from a group of scientists, headed by Viktor Gurfinkel. Shik and Orlovsky (cf. 1976), for instance, discovered that a mesencephalic cat can still walk when supported against gravity, a finding that was the talk of the day in Moscow.<sup>55</sup> Furthermore, Anatol Fel’dman came to realize that motor control may target the threshold of the stretch reflex, the “lambda model,”<sup>56</sup> implying that force is not normally controlled, but rather the equilibrium point.

In 1967, a compilation of Bernstein’s papers was published in English (Bernstein, 1967). His seminal conception of “coordination” inspired Peter Greene in the United Kingdom (e.g., 1972), and then Michael Turvey (e.g., 1990), and Scott Kelso (1995) in the

<sup>52</sup>Bernstein, 1965, cited from Bongaardt, 1996, p. 95.

<sup>53</sup>Meijer & Bongaardt, 1998; Feigenberg & Meijer, 1999.

<sup>54</sup>Pasternak, 1964, p. 70, cited from Bongaardt, 1996, p. 47; original poem in Russian.

<sup>55</sup>The KGB heard of it and invited the group to construct computer-controlled cats to spy in the White House (Fel’dman, Gurfinkel, Shik, personal communications).

<sup>56</sup>For instance, Fel’dman 1986; see also: Meijer, Kots & Edgerton, 2001. Note that Bizzi’s model of alpha-control (e.g., Bizzi et al., 1982), although historically related, is different in principle from Fel’dman’s model.



United States. John Whiting edited a republication of the 1967 book, together with chapters that discussed contemporary relevance (Whiting, 1984). In the Soviet Union, Petr Anokhin, Josif Feigenberg, and Yakov Kots did much to keep the heritage alive. Friends would often meet in private, behind closed curtains (Pickenhain, personal communication), and in the German Democratic Republic, Lothar Pickenhain succeeded in publishing a translation of Bernstein's papers under the rather innocent title "Movement Physiology."<sup>57</sup>

There is, of course, the risk that we admire Bernstein because we need the mythology of a founding father. Still, his relentless search for the biology of movement, and thus, of the brain, is inspiring in and of itself. For centuries, science was unable to avoid dualism, and the very fact that dialectical materialism was the official philosophy of the Soviet Union may have facilitated Bernstein in discovering some basic principles of biological organization, that is the coordination of movement (and of the brain). Moreover, it is awe-inspiring to see how human beings could survive and could thrive under the terror of Stalinism. In fact, the adverse forces of neoPavlovianism appear to have led Bernstein further on his own path, rather than distracted him. There is human solace in that interpretation.

The subtitle of our paper—the double-edged sword of Stalinism—suggests that both dialectical materialism and the neoPavlovian coup contributed to the development of Bernstein's theory. Not many Russian colleagues will agree with our armchair analysis. But then, intelligence may be stochastic and could work in ways very different from what Pavlov believed. In his attack of Köhler's monkey work, Pavlov concluded:

When the ape becomes tired, as a result of his unsuccessful efforts [to take hold of the fruit], he gives up and remains for some time in sitting posture. When he has rested he tries again and succeeds in accomplishing his task. According to Köhler, the ape's intelligence is proved by the fact that he sits for a period without doing anything. He literally says that, gentlemen. In his view the ape accomplishes some kind of intellectual work when it is sitting, and this proves its intelligence. How do you like it? It turns out that nothing but the silent inaction of the ape proves its intelligence!<sup>58</sup>

## References

- Adrian ED, Buytendijk FJJ (1931): Potential changes in the isolated brain stem of goldfish. *Journal of Physiology* 71: 121–135.
- Akademija Nauk SSSR, Akademija Meditsinskikh Nauk SSSR (1950): *Nauchnaja Sessija Posvyashchennaja Probleme Fiziologicheskogo Uchenija Akademika I.P. Pavlova* [Scientific Session Dedicated to the Problems of the Physiological Theory of Academician I.P. Pavlov]. Moscow: Izdatel'stvo Akademii Nauk SSSR. (Stenographical account, 28 June – 4 July.)
- Aksyonov V (1993–1994): *Moskovskaja saga: Trilogija* [Moscow Saga: A trilogy]. Moscow: Tekst. (Appeared in English translation under the title: Generations of Winter.)
- Andronov AA, Chaikin CE (1937/1949) *Theory of Oscillations*. Princeton, NJ: University Press. (Original work in Russian.)
- Bailes KE (1977): Alexei Gastev and the Soviet controversy over Taylorism, 1918–1924. *Soviet Studies* 29: 373–394.

<sup>57</sup>Pickenhain & Schnabel, 1975/1988. Such publishing a "dissident's" (i.e., Bernstein's) view, was not done in the German Democratic Republic, but Pickenhain was careful enough to get away with it (cf. Bongaardt, Pickenhain & Meijer, 2000).

<sup>58</sup>Pavlov 1934b/1955, pp. 558–559.

- Beek PJ, Meijer OG (1999): Spinal anticipation and cortical correction: Coordination of movements (1930). *Motor Control*, 3, 2–8. (Contains an English translation of Bernstein's 1930 article on Coordination of Movements in the *Bol'saya Medicinskaja Enciclopedija*, Volume 13, pp. 755–757. Moscow: Medgiz.)
- Bernstein NA (1924): Troduvye tranirovki i uslovnye refleksy [Work movements and conditioned reflexes]. *Organiztsiia Truda* 84. (Reference courtesy of Irina Sirotkina.)
- Bernstein NA (1927): Analyse aperiodischer trigonometrischer Reihen [The analysis of aperiodic trigonometric series]. *Zeitschrift für angewandte Mathematik und Mechanik* 7: 476–185.
- Bernstein NA (1935/1988): Das Problem der Wechselbeziehungen zwischen Koordination und Lokalisation [The problem of the interrelationships between coordination and localization]. In: Pickenhain L & Schnabel G, eds., *Bewegungsphysiologie von N.A. Bernstein* (2nd ed., pp. 67–98). Leipzig, Johann Ambrosius Barth. (Original work published in Russian.)
- Bernstein NA (1936/2003): *Sovremennye Iskaniia v Fisiologii Nervnogo Protsessa* [Contemporary Research on the Physiology of the Nervous System]. Edited by Josif Feigenberg and Irina Sirotkina. Moscow: Smysl. (Reference courtesy of Irina Sirotkina.)
- Bernstein NA (1945–1946/1996): On dexterity and its development. In: Latash ML, Turvey MT, eds., *Dexterity and its Development* (pp. 3–244). Mahwah, NJ, Lawrence Erlbaum. (Original Russian manuscript written in 1945–1946 and published in 1991.)
- Bernstein NA (1947): *O Postroenii Dvizanii* [On the Construction of Movements]. Moscow, Medgiz.
- Bernstein NA (1967): *The Co-ordination and Regulation of Movements*. Oxford, UK, Pergamon Press.
- Bizzi E, Accornero N, Chapple W, Hogan N (1982): Arm trajectory formation in monkeys. *Experimental Brain Research* 46: 139–143.
- Bongaardt R (1996): *Shifting Focus: The Bernstein Tradition in Movement Science*. Amsterdam, Rob Bongaardt. (PhD Thesis.)
- Bongaardt R, Meijer OG (2000): Bernstein's theory of movement behavior: Historical development and contemporary relevance. *Journal of Motor Behavior* 32: 57–71.
- Bongaardt R, Pickenhain L, Meijer OG (2000): Bernstein's anti-reductionistic materialism: On the road towards a biology of activity (1965). *Motor Control* 4: 377–406. (Contains an English translation of Bernstein's 1965 paper, that appeared in *Voprosy Filosofii* 19: 65–78.)
- Braune W, Fischer O (1895–1904): Der Gang des Menschen [Human gait]. *Abhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften*, 21, 25, 26 & 28. (6 Volumes.)
- Feigenberg IM (1988): Chronologisches Verzeichnis aller Publikationen N.A. Bersteins [Chronological list of all Bernstein's publications]. In: Pickenhain L, Schnabel G, eds., *Bewegungsphysiologie von N.A. Bernstein* (pp. 255–263). Leipzig, Barth.
- Feigenberg IM (2004): *Nikolai Bernstein: Ot Refleksa k Modeli Budushchego* [Nikolai Bernstein: From the Reflex to the Model of the Future]. Moscow, Smysl.
- Feigenberg IM, Latash LP (1996): N.A. Bernstein: The reformer of neuroscience. In: Latash ML, Turvey MT, eds., *Dexterity and its Development* (pp. 247–275). Mahwah, NJ, Lawrence Erlbaum.
- Feigenberg IM, Meijer OG (1999): The active search for information: From reflexes to the model of the future (1966). *Motor Control* 3: 225–236. (Contains an English translation of Bernstein's 1966 paper, that appeared posthumously in the popular weekly *Nedelja* 20: 8–9.)
- Fel'dman AG (1986): Once more on the equilibrium point hypothesis (lambda model) for motor control. *Journal of Motor Behavior* 18: 17–54.
- Fel'dman AG, Meijer OG (1999): Discovering the right questions in motor control: Movements (1929). *Motor Control* 3: 105–134. (Contains an English translation of Bernstein's 1929 article on Movements in the *Bol'saya Medicinskaja Enciclopedija*, Volume 8, pp. 451–474 & 479–480. Moscow, Medgiz.)
- Flesher MM (1997): Repetitive order and the human walking apparatus: Prussian military science versus the Webers' locomotion research. *Annals of Science* 54: 463–487.
- Gel'fand IM, Gurfinkel VS, Fomin SV & Tsetlin ML (1971): In memory of N.A. Bernstein. In: Gel'fand IM, Gurfinkel VS, Fomin SV & Tsetlin ML, eds, *Models of Structural Functional Organization of Certain Biological Systems* (pp. xxxiii–xxxv). Cambridge, MA, MIT.

- Gel'fand IM, Latash ML (1998): On the problem of adequate language in motor control. *Motor Control* 2: 306–313.
- Gel'fand IM, Tsetlin ML (1961): The principle of nonlocal search in automatic optimization systems. *Soviet Physics Doklady* 6: 192–194.
- Graham LR (1987): *Science, Philosophy and Human Behavior in the Soviet Union*. New York, NY, Columbia University Press.
- Greene PH (1972): Problems of organization of motor systems. In: Rosen R, Snell FH, eds., *Progress in Theoretical Biology, Volume 2* (pp. 303–338). New York, NY, Academic Press.
- Gregory F (1977): *Scientific Materialism in Nineteenth Century Germany*. Dordrecht, Reidel.
- Gurfinkel VS, Cordo PJ (1998): The scientific legacy of Nikolai Bernstein. In: Latash ML, ed., *Progress in Motor Control, Volume 1: Bernstein's Traditions in Movement Science* (pp. 1–19). Champaign, IL, Human Kinetics.
- Hafner S (1979): *Preussen ohne Legende* [Prussia without Legend]. Hamburg, Gruner.
- Haken H (1977): *Synergetics: An Introduction*. Heidelberg, Springer.
- Huxley TH (1874/1893): On the hypothesis that animals are automata and its history. In: Huxley TH, ed., *Collected Essays, Volume 1* (pp. 315–320). London, MacMillan.
- Judt, T. (2005). *Postwar: A History of Europe Since 1945*. New York, NY: Penguin Books.
- Kay BA, Turvey MT, Meijer OG (2003): An early oscillator model: Studies on the biodynamics of the piano strike (Bernstein & Popova, 1930). *Motor Control* 7: 1–45. (Contains a translation of Bernstein's and Popova's paper as appeared in the *Proceedings of the Piano-Methodological Section of the State Institute of Music Science, Volume 1* pp. 5–47; the paper appeared in a German version in *Arbeitsphysiologie I*: 396–432.)
- Kelso JAS (1995): *Dynamic Patterns: The Self-organization of Brain and Behavior*. Cambridge, MA, MIT Press.
- Kozulin A (1984): *Psychology in Utopia: Towards a Social History of Soviet Psychology*. Cambridge, MA, MIT Press.
- Latash LP, Latash ML, Meijer OG (1999): 30 Years later: The relation between structure and function in the brain from a contemporary point of view (1966), Part I. *Motor Control* 3: 329–345. (Contains the first half of the 1966 paper by Bassin, Bernstein, and Latash, that appeared in: Gratchenkov NI, ed., *Physiology in Clinical Practice*, pp. 38–71. Moscow, Nauka.)
- Latash LP, Latash ML, Meijer OG (2000): 30 Years later: The relation between structure and function in the brain from a contemporary point of view (1966), Part II. *Motor Control* 4: 125–149. (Contains the second half of the 1966 paper by Bassin, Bernstein, and Latash, that appeared in: Gratchenkov NI, ed., *Physiology in Clinical Practice*, pp. 38–71. Moscow, Nauka.)
- Latash ML (2005): A new biography of Nikolai Bernstein. *Motor Control* 9: 1.
- Lekthman YB (1963): [Discussion of Bernstein's paper.] In: Akademija Nauk SSSR Institut Filosofii, *Filosofskije Voprosy Fizologii Vysshei Nervnoi Dejatel'nosti i Psikhologii* (pp. 552–559). Moscow, Izdatel'stvo Akademii Nauk SSSR.
- Meijer OG (2001): Making things happen: An introduction to the history of movement science. In: Latash ML, Zatsiorsky VM, ed., *Classics in Movement Science* (pp. 1–57). Champaign, IL, Human Kinetics.
- Meijer OG (2002): Bernstein versus Pavlovianism: An interpretation. In: Latash ML, ed., *Progress in Motor Control, Volume 2: Structure-Function Relations in Voluntary Movements* (pp. 229–250). Champaign, IL, Human Kinetics.
- Meijer OG, Bongaardt R (1998): Bernstein's last paper: The immediate tasks of neurophysiology in the light of the modern theory of biological activity (1966). *Motor Control* 2: 2–9. (Contains an English translation of Bernstein's paper, published in the *Proceedings of the XVIIIth International Congress of Psychology*, Moscow, August 4–11, 1966.)
- Meijer OG, Wagenaar RC (1998): Bernstein's rejection of Braune and Fischer: Studies on the physiology and pathology of movements (1936). *Motor Control* 2: 95–100. (Contains an English translation of Bernstein's 1936 paper, that appeared in the *Physiological Journal of the USSR* 21: 1017–1019.)

- Meijer OG, Feigenberg IM (2000): Bernstein's failure to join the space race: His commentary on Tsiolkovskii's "Mechanics in biology" (1964). *Motor Control* 4: 262–272. (Contains an English translation of Bernstein's 1964 paper, that appeared in: Tsiolokovskii KE, *Sobranie Sochinenii, Volume 4*, pp. 454–458.)
- Meijer OG, Kots YM, Edgerton VR (2001): Low-dimensional control: Tonus (1963). *Motor Control* 5: 1–22. (Contains an English translation of the 1963 article by Bernstein and Kots, that appeared in the *Grand Medical Encyclopaedia*, second edition.)
- Pavlov IP (1932a/1955): Reply of a physiologist to psychologists. In: *I.P. Pavlov: Selected Works* (pp. 409–447). Moscow, Foreign Language Publishing House. (Original publication in the *Psychological Review* 39.)
- Pavlov IP (1932b/1955): Dynamic stereotypy of the higher part of the brain. In: *I.P. Pavlov: Selected Works* (pp. 448–453). Moscow, Foreign Language Publishing House. (Original statement to the occasion of the Tenth International Congress of Psychologists in Copenhagen.)
- Pavlov IP (1934a/1955): [Criticism of the Gestalt psychology.] In: *I.P. Pavlov: Selected Works* (pp. 569–576). Moscow, Foreign Language Publishing House. (Original statement in Russian.)
- Pavlov IP (1934b/1955): The nature of intelligence in anthropoids and the erroneous interpretation of Koehler. In: *I.P. Pavlov: Selected Works* (pp. 558–562). Moscow, Foreign Language Publishing House. (Original statement in Russian.)
- Pavlov IP (1935/1955): [Speech at the opening of the fifteenth international physiological congress.] In: *I.P. Pavlov: Selected Works* (pp. 56–58). Moscow, Foreign Language Publishing House.
- Pickenhain L (1998): Das Schicksal der Pawlowschen Ideen in der UdSSR [The fate of Pavlov's ideas in the Soviet Union]. In: Pickenhain L, ed., *I.P. Pavlov: Gesammelte Werke über die Physiologie und Pathologie der höheren Nerventätigkeit* (pp 373–406). Würzburg, Ergon.
- Pickenhain L, Schnabel G, eds. (1975/1988): *Bewegungsphysiologie von N.A. Bernstein* [N.A. Bernstein's Movement Physiology]. Leipzig, Johann Ambrosius Barth.
- Prigogine I, Stengers, I (1984): *Order out of Chaos*. New York, NY, Bantam.
- Regelmann JP (1980). *Die Geschichte des Lyssenkoismus* [The History of Lysenkoism]. Frankfurt, Rita Fischer Verlag.
- Sherrington C (1906): *The Integrative Action of the Nervous System*. New York, NY, Charles Scribner's Sons.
- Shik ML, Orlovsky GN (1976): Neurophysiology of locomotor automatisms. *Physiological Review*, 55: 465–501.
- Sirotkina IE (1995): N.A. Bernshtein: The years before and after "the Pavlov session." *Russian Studies in History Fall 1995*: 24–36.
- Sirotkina IE (1996): Vydaiuschiisia fiziolog. Klassik psikhologii? [An outstanding physiologist. A classic of psychology?] *Psikhologicheskii Zhurnal V. 17 no. 5*: 116–127. (Reference courtesy of Irina Sirotkina.)
- Smirnov KM (1954). [Discussion.] In: *Wisenschaftliche Tagung über die Probleme der physiologischen Lehre I.P. Pavlov's, gemeinsam durchgeführt von der Akademie der Wissenschaften und der Akademie der Medizinischen Wissenschaften der UdSSR in Moskau, 28. Juni bis 4. Juli 1950, 4. Heft* [Scientific Meeting on the problems of the physiological theory of I.P. Pavlov, organized by the Academy of Sciences and the Academy of Medical Sciences of the Soviet Union, June 28 – July 4, 1950, in Moscow, Volume 4] (pp. 520–524). Berlin, Verlag Kultur und Fortschritt. [German translation of the stenographical notes.]
- Sporns O, Edelman GM, Meijer OG (1998): Bernstein's dynamic view of the brain: The current problems of modern neurophysiology (1945). *Motor Control* 2: 283–305. (Contains an English translation of Bernstein's article, which appeared in the *Physiological Journal of the USSR* 31, 5/6: 298–311.)
- Todes DP (1995): Pavlov and the Bolsheviks. *History and Philosophy of the Life Sciences* 17: 379–418.

- Turvey MT (1990): Coordination. *American Psychologist* 45: 938–953.
- Ueberhorst H (1980): *Geschichte der Leibesübungen, Band 3/1* [History of Physical Exercise, Volume 3/1]. Berlin, Bartels & Wernitz.
- Wagenaar RC, Meijer OG (1998): Bernstein's revolution in movement medicine: Coordination disorders and the recovery of walking biodynamics after cerebrovascular injuries (1954). (Contains an English translation of Bernstein's 1954 paper, with G.R. Buravtseva, that appeared in the *Proceedings of the VIIth Meeting of the Scientific Institute of Neurology of the Academy of Medical Sciences of the USSR* (pp. 28–30). Moscow, Academy of Medical Sciences.)
- Weber W, Weber E (1836/1991): *Mechanics of the Human Walking Apparatus*. Berlin, Springer. (Original edition in German.)
- Whiting HTA (1984): *Human Motor Actions: Bernstein reassessed*. Amsterdam, North Holland.